

Description of Analytical Tools

Name: Water Evaluation And Planning (WEAP)

Author: Stockholm Environment Institute (SEI)

Availability of Technical Support: Stockholm Environment Institute - Boston Centre, 11 Arlington Street, MA 02116, USA, <http://www.seib.org>

Categories: WEAP is a scenario-driven decision support tool that facilitates integrated analysis of current and future water supply and demand while accounting for multiple and competing uses of water, making possible evaluation of a full range of water development and management options under a given set of water allocation priorities, economic considerations, and water quality-, land use- and climate-driven impacts on water supply and demand. Analyses can be performed at any appropriate spatial and temporal scale and level of aggregation warranted by data availability.

Main Features and Capabilities:

- Spatial scale: flexible, local to regional system characterization, depending only on analytical objectives and data availability.
- Temporal scale: flexible from *daily to annual time steps*.
- Characterizes the engineered and biophysical components of supply along with human and ecologic demands to facilitate policy-relevant decision-making.
- Forecasts demand-side variables (water use patterns; pollution generation, treatment and discharge; equipment efficiencies; re-use; pricing and allocation priorities) jointly with supply (streamflow with optional streamflow generation with imbedded rainfall-runoff model, groundwater, groundwater-surface water interactions, reservoir operations, water quality, and water transfers).
- Simulates stream water quality (temperature, salinity, DO, BOD, total suspended solids (TSS)) and other conservative (simple mixing) or non-conservative (assuming first-order decay) constituents.
- Eliminates the need for post-analysis linkage of output from models that treat water demand and supply separately.
- Allows supply and demand drivers to vary step-wise through time from current conditions, facilitating detailed characterization of water conditions throughout the entire analysis period.

Applications: WEAP has been applied in over 30 water evaluation projects around the world, including the U.S.A., China, Thailand, India, Mexico, Brazil, Germany, Korea, Ghana, Kenya, South Africa, Egypt, Israel and Oman.

Calibration/Validation/Sensitivity Analysis: (See the WEAP21 website at weap21.org and go to the publication link to find validation studies). The model includes an Applications Programming Interface (API), which has been linked to the parameter estimation freeware, PEST (<http://www.scisoftware.com/>).

Peer Review:

Yates, D., Sieber, J., D. Purkey, A. Huber-Lee. "WEAP a demand, priority, and preference driven water planning model: Part 1, Model characteristics," *Water International*, in press.

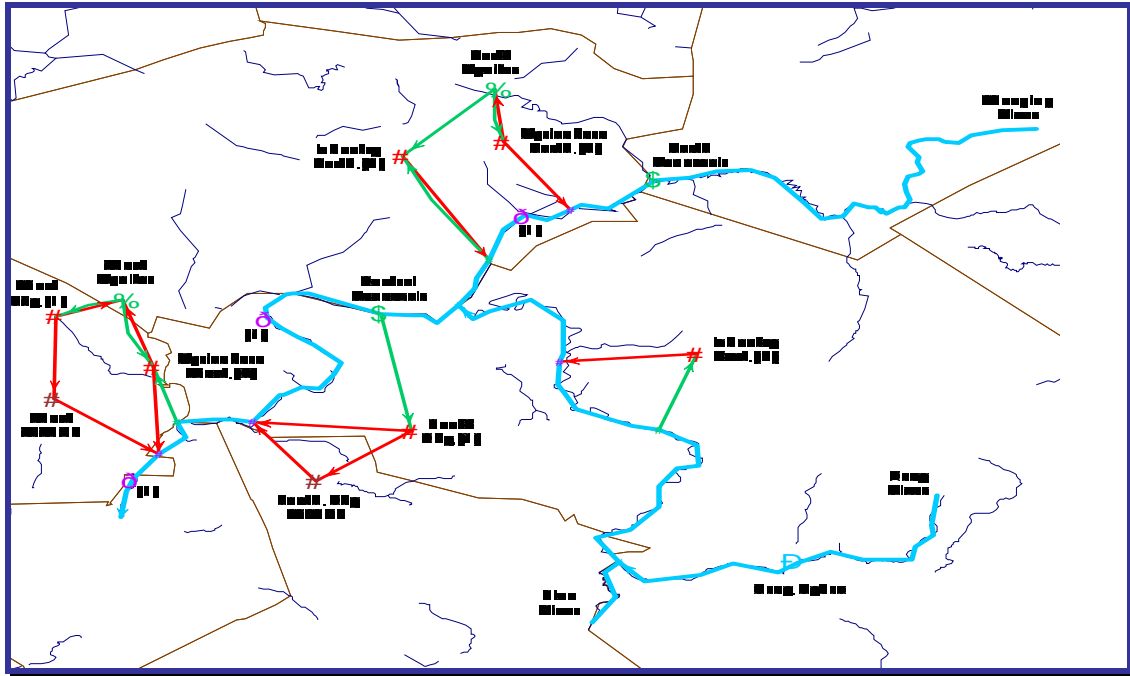
Yates, D., D. Purkey, H. Galbraith, A. Huber-Lee, J. Sieber. "WEAP: A demand, priority, and preference driven water planning model: Part 2, Evaluating freshwater ecosystem services," *Water International*, in press.

Yates, D., D. Purkey, J. Sieber, A. Huber-Lee, H. Galbraith, J. West, and S. Herrod-Julius. "A physically-based water resource planning model of the Sacramento Basin, California, USA," *Submitted to ASCE Journal of Water Resource Management*.

Anatomy of WEAP:

Conceptual Basis. WEAP operates on the basic principle of water balance accounting, where both the engineered and biophysical components of a water system are represented to facilitate multi-stakeholder water management dialogue on a broad range of topics, including sectoral demand analysis, water conservation, water rights and allocation priorities, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, and project benefit-cost analysis. WEAP informs management strategies through scenario-driven analyses of possible water futures where the influences of climate, land use management, demand, regulation, and planning objectives can be explored. These analyses can be conducted at any number of scales, from municipal water systems and the local catchments to regional, transboundary river systems.

Demand (e.g., industrial water use, watershed and agricultural demands through evapotranspiration, and ecosystem requirements) and supply (e.g., precipitation excess, reservoirs, groundwater, desalination plants, etc) components of a water system are represented in graphical, schematic form with a set of model objects and processes, such as transmission and return flows, wastewater treatment, in-stream chemical degradation or production. Embedded in these objects are a set of transparent allocation, operation, and water quality constraints input by the user. The data structure and level of detail can be easily customized to meet the requirements of a particular analysis. An example WEAP schematic is shown below.



All applications generally include several steps. The *Study Definition* sets up the time frame, spatial boundary, system components and configuration of the problem. The *Current Accounts*, which can be viewed as a calibration step in the development of an application, provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. *Key assumptions* may be integrated into the Current Accounts to represent the policies, costs and driving factors that affect demand, pollution, supply and hydrology. *Scenarios* built on the Current Account would allow exploring the impact of alternative assumptions or policies on future water availability and use. Scenario output can be evaluated based on any user-defined criteria, such as water sufficiency, costs and benefits, compatibility with environmental targets and sensitivity to key variables.

Theoretical Basis: WEAP maximizes water coverage (percent of demand satisfied) for all human and ecosystem demands, subject to mass balance, demand priorities, supply preferences and other constraints (e.g. system storage and conveyance capacities). WEAP employs a priority-based optimization algorithm that uses a concept of Equity Groups to allocate water in times of insufficient supply.

All water entering the system in a given time step is available for use throughout the system within that time step. Moreover, any water returned to sources after use by one demand site is available for other demand sites within the same time step. Any water not committed to storage in a reservoir, aquifer or snow pack exits the system via evapotranspiration, demand site consumption, or streamflow flushing. In this way, each time step is independent of the previous one, except for carry-over of reservoir and aquifer storage.

Numerical Basis: WEAP calculates a mass balance for water and pollutant at every node and link in the system and uses a Linear Programming (LP) algorithm to dispatch water to demand sites. This LP has as its objective function maximizing supply to demand sites subject to demand priorities (e.g., instream flow requirement satisfied before irrigation needs), supply preferences (e.g. groundwater versus river water), and system constraints (e.g., inflow to a demand site can not exceed its supply requirement). Because WEAP tries to satisfy all demand sites having the same priority equally, additional constraints are added to the LP. Each coverage variable is set to a new variable that represents the final coverage to ensure coverage equity among demand sites. A “slack” variable included in the LP formulation determines which demand sites are constrained from receiving higher allocations and which can get more water when supply is limited. The LP solves all equations simultaneously.

Demand sites are allocated water depending on demand priorities and supply preferences. WEAP iterates for each priority and preferences, so that demands with priority 1 are allocated water before those with priority 2. Thus, LP is solved at least once for each priority for each time step. When solving for priority 1, WEAP will temporarily turn off allocations to demands with priority 2 and lower. After priority 1 allocations have been, priority 2 demands are turned on (but 3 and lower are still turned off). In cases where there is not enough water to satisfy all demands with the same priority, WEAP tries to satisfy all demands to the same percentage of their demand.

At each time step, the calculations follow the same order:

- Annual demand and monthly supply requirements for each demand node and flow requirements are calculated.
- Runoff and infiltration from catchments.
- Inflows and outflows of water for every node and link in the system. This includes calculating withdraws from supply sources to meet demand, and dispatching reservoirs. This step is solved by a Linear Programming (LP) routine which attempts to optimize coverage of demand site and instream flow requirements subject to demand priorities, supply preferences and mass balance and other constraints.
- Pollution generation by demand sites, flows and treatment of pollutants and loadings on receiving bodies, concentrations in rivers.
- Hydropower generation.

Inputs and Outputs: Data requirements for WEAP are dependent on the questions being explored and the level of system detail and disaggregation desired. Data output includes an extensive set of variables that quantify water allocation and water fluxes.

Inputs: Following is a partial list of key input categories:

- **System Layout:** An schematic network of nodes and links representing the physical system, e.g.; demand sites, sources of supply, storage and conveyance (transmission link), catchment, wastewater treatment plants.

- **Key Assumptions:** Major modeling assumptions that drive system simulations, e.g., population growth, unit cost of water.
- **Demand Sites Disaggregation:** Sector (e.g., agriculture, urban), Sub-sector (e.g., crop-type, livestock, food processing, textile, paper factory), End-Use (e.g., water use in different soil types, irrigation techniques, cooling towers, sanitary plants), Device (e.g., sprinkler, drip irrigation devices, shower heads, toilets and washing machines).
- **Demand Sites Calculation Methods:** Standard method, FAO crop requirement approach, Direct method.
- **Demand Sites Water use:** Consumptive and non-consumptive uses, loss and re-use rates.
- **Demand-Side Management (DSM):** Water savings through demand management strategies; aggregated/disaggregated approach.
- **Demand Priority:** Input to signify a demand site's priority for a specific supply. Priority 1 signifies the highest priority.
- **Catchments:** Land use (area, irrigated area, crop coefficient, effective precipitation), Yield (potential yield, factor, price), root zone water capacity and conductivity, Leaf Area Index (to control surface run-off response), Climate (precipitation, temperature, humidity, wind, melting point, freezing point, latitude, initial snow accumulation value at the beginning of the first month of the simulation).
- **Supply and Resources Transmission Links:** Linking demand sites and supply sources via transmission links, maximum physical or contractual carrying capacity, transmission losses, cost of delivered water.
- **Hydrologic Conditions and Inflows:** Water Year Method, Catchment runoff and Infiltration, Read from File Method, Mathematical Expressions Method.
- **Supply Preference:** Each demand site with multiple sources can specify its "preference" for a specific source due to economic, environmental, historical, legal or political reasons. Preference 1 signifies the highest preference. Supply preference is assigned to the transmission link connecting the demand site to supply source.
- **Rivers and Diversions:** Headflows information (Water-Year method, Catchment method, Expression method, Read-from-File method), max. diversion, stream flow gauge, water quality information at river headflow or at a "receiving" point for simple mixing as well as river reach information (distance marker, stage-flow-width curve) needed for first-order decay of non-conservative constituents.
- **River Reaches:** Inflows and Outflows (from/to hydraulically connected groundwater), inflows from surface water, evaporation, reach length, climate data to model river temperature (air temperature, humidity, wind, latitude).
- **Groundwater:** Initial and total GW storage capacity, max. GW withdrawal, GW recharge, GW and Surface water interactions (hydraulic connection; river depth, GW storage to river level, specific yield,

hydraulic conductivity, horizontal distance), GW water quality entering surface water system.

- **Reservoirs:** Initial and total storage capacity, inflows, elevation-volume curve, reservoir evaporation, Reservoir priority (for filling; **Note:** a reservoir is considered a demand site when filling), reservoir zones and operation (flood control zone, conservation zone, buffer zone, inactive zone), hydropower generation (min and max turbine flows, tailwater elevation, plant factor, generating efficiency)
- **Other Supplies:** These are supply sources that have no storage capacity and represent non-river system supplies, e.g., desalination plants, inter-basin water transfers, or water imports.
- **Return flows:** Fraction of demand site outflow or wastewater treatment plant outflow that is sent to each return flow destination, losses in return links.
- **Wastewater Treatment:** Consumptive losses, removal rate of pollutants, outflow concentration, daily capacity.
- **Minimum Flow Requirement:** Input information that specifies the minimum monthly flow required along a river reach to meet water quality, fish & wildlife, navigation and recreation, downstream or other requirements. Depending on its demand priority specified, a flow requirement will be satisfied either before or after other demands on the system.

Outputs: Main output categories are as follows;

- **Water Supply Allocation:** water demand, supply requirement, supply delivered, unmet demand, coverage (percent of demand satisfied), demand-node mass balance, Instream flow requirements (delivered, unmet, coverage).
- **Supply and Resources:** *Inflows to Area* (accounting for all inflows entering the system; e.g. river headflows, surface water inflows to reaches, groundwater recharge, local reservoir inflows, other local supply inflows (desalinations or inter-basin water transfer), catchment precipitation. *Outflow from Area* (accounting for all water leaving the system; e.g. consumption at demand sites (ag and urban), catchment ET, evaporation from river reaches and reservoirs, losses in transmission links, groundwater and local reservoir outflows, losses in wastewater treatment plants, outflows from the end of rivers that do not flow back into other rivers; i.e. flow to salt sinks. **Note:** Total overall inflows to the system may not equal the overall outflows from the system due to change in storage in reservoirs and groundwater.
- **River:** Stream flow, Stage, Velocity
- **Groundwater:** Storage, Inflows and Outflows, Overflow, Height above river, Outflow to river.
- **Reservoir:** Storage volume, Storage elevation, Inflows and Outflows, Hydropower.
- **Transmission link:** Flow, Inflows and Outflows

- **Other Supply:** Inflows and Outflows to check the mass balance on “Other Supply” sources; e.g. desalination plants, inter-basin water transfer.
- **Return Link:** Flow, Inflows and outflows
- **Catchment:** Inflows and Outflows, snow melt, snow accumulation, infiltration/runoff, ET, soil moisture, flow to surface water and groundwater.
- **Environmental Water Quality:** Pollution generation, Pollution loads, Pollution inflow to treatment plants, Wastewater treatment plant inflows and outflows, surface water quality (Conservative or First-Order decay constituents, Temperature, Salinity, DO, BOD, TSS; Total Suspended Solids)

Data Management:

Data management in WEAP is structured based on five set of on-screen “views” which handle data management related to solution area:

1- Schematic View: This is the starting point and a central feature of WEAP where a schematic network of nodes and links representing the actual system is created. A “drag and drop” graphical interface is used to describe, visualize and edit the physical features of the water supply and demand. GIS layers can be added for clarity and impact. This feature provides a one-click access to the entire analysis- a “right” click on any element in the schematic accesses the “data” behind the element and the “results” for that element.

2- Data View: Data structure, modeling functions and assumptions are created in this view. In Data view, screen is divided into four panes. On the top left, a hierarchical tree is used to create and organize data structures under six major categories of Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumption. The tree is also used to select the data to be edited, which is shown on the right of the screen. For example, clicking on the “Demand Sites” tree branch on the left of the screen, will display the data for all demand sites on the right of the screen. On the top-right of the screen, a data entry table is used to edit data and created modeling relationships. The information entered here is displayed graphically in the bottom right pane.

3- Results View: This view displays a wide variety of charts and tables covering each aspect of the system: demand, supply, costs and environmental pollution loading. Output reports can be customized and viewed for one or more scenarios. Also, “Favorite” option can be used to bookmark the most useful charts for further analysis or presentations.

4- Overviews View: In this view, the “Favorite” charts created in the earlier “Results” view are grouped together which can be displayed on the screen. This gives a bird’s-eye view of different important aspects of the system, such as demands; coverage, storage levels, environmental impacts and costs.

5- Notes View: This is a simple word-processing tool which can be used for documentation and references of each branch of the tree. To edit the notes, either type

directly into the Notes Window, or select Edit to display a larger window with additional word-processing features. Use Print button to print or Word buttons to export information in the Notes view to Microsoft Word.

Software Requirements: WEAP requires a 200 MHz or faster Pentium class PC with Microsoft Windows 95 or later (a 400 MHz PC with Windows 98 or later is recommended). A minimum of 128 MB of RAM and 50 MB of free hard disk space is also required (at least 256 MB of RAM recommended). In addition, Microsoft Internet Explorer version 4.0 is required for viewing WEAP's HTML Help. The computer screen should be set to a minimum resolution of 800x600, but preferably even higher (e.g., 1024x768 or 1280x1024), to maximize the presentation of data and results. An internet connection is not required, but is useful for tasks such as emailing data sets and receiving automatic updates to the software. WEAP can also communicate with Microsoft Excel and Microsoft Word, but they are not required. WEAP is designed as a single-user system. It is not intended as multi-user system and it is not recommended running it from a shared network drive.

When WEAP starts up, it will automatically check the WEAP ftp site for software updates (if your computer is connected to the Internet). If any updates are found, you will be asked for an option for automatic download and installation.